APPENDIX D

AIR QUALITY IMPROVEMENT PROGRAM (AQIP) AND LOW CARBON TRANSPORTATION GREENHOUSE GAS REDUCTION FUND (GGRF) INVESTMENTS

MULTI-SOURCE FACILITY DEMONSTRATION PROJECT

METHODOLOGY FOR DETERMINING EMISSION REDUCTIONS AND COST-EFFECTIVENESS

The methodology below must be used to calculate the emission reductions and cost-effectiveness of projects proposed by this Solicitation. All calculations and assumptions made must be shown clearly and in their entirety in the application (Appendix A, Attachment 4).

All calculations will use diesel fuel usage of the baseline vehicle or equipment as a basis for the greenhouse gas (GHG) and criteria pollutant emission calculations. This technique may not adequacy capture the emission profiles of all proposed applications however, this technique is used to allow all submitted applications to be scored on a level playing field.

GHG emission calculations are based on life cycle analysis (well-to-wheel). Criteria pollutant and PM emission calculations are based on exhaust emissions (tank-to-wheel). The GHG emission factors below are excerpted from the 2015 Low Carbon Fuel Standard (LCFS) regulatory documents. Please note that while the LCFS fuel carbon intensity values may change during the Solicitation period, project applicants must use the values listed in this appendix. The remaining emission factors and methodology below are from the Board approved 2011 Carl Moyer Program Guidelines (Moyer Guidelines) Appendices C, D, and G, as amended in July 2014 and updated in December 2014. Language has been modified where necessary for the purposes of this Solicitation. The complete Moyer Guidelines, including all of its appendices, can be found at http://www.arb.ca.gov/msprog/moyer/guidelines/current.htm.

If a proposed project is for an application that uses a baseline diesel engine of 24 hp or lower, for the purpose of this solicitation and to calculate the needed emission reductions and cost effectiveness, use the relevant Carl Moyer tables for a 25 hp baseline diesel engine.

Any examples provided here are for reference only and do not imply additional demonstration project types or categories, nor do Carl Moyer Program funding amounts limit the amount of funding that may be available for demonstration projects. Criteria pollutant and PM Table numbers are kept the same as those in the current Moyer Guidelines.

Emission Factors for GHG: 2015 Proposed Re-Adoption of LCFS

- Table MSF App D1: Fuel Energy Density[1]

Fuel (units)	***Energy Density***
CARBOB (gal)	119.53 (MJ/gal)
CaRFG (gal)	115.63 (MJ/gal)
Diesel fuel (gal)	134.47 (MJ/gal)
CNG (scf)	0.98 (MJ/scf)
LNG (gal)	78.83 (MJ/gal)
Electricity (KWh)	3.60 (MJ/KWh)
Hydrogen (kg)	120.00 (MJ/kg)
Denatured Ethanol (gal)	81.51 (MJ/gal)
FAME Biodiesel (gal)	126.13 (MJ/gal)
Renewable Diesel (gal)	129.65 (MJ/gal)

[1] Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Proposed Re-Adoption of the Low Carbon Fuel Standard, December 2014 (http://www.arb.ca.gov/regact/2015/lcfs2015/lcfs15isor.pdf)

- Table MSF App D2: Fuel Carbon Intensity Values[2]

	Fuel	Pathway Identifier	Carbon Intensity Values (gCO_2e/MJ)
Baseline Fuels	CARBOB – based on the average crude oil supplied to California refineries and average California refinery efficiencies	CBOB001	100.53
	ULSD – based on the average crude oil supplied to California refineries and average California refinery efficiencies	ULSD001	102.76
	CaRFG (calculated)	--	99.11
Natural Gas	North American NG – CNG	CNG002	79.46
	North American NG – LNG (90% liquefaction eff.)	LNG002	86.57
Biomethane	Landfill Gas – CNG	CNG003	19.21
	Landfill Gas – LNG (90% liquefaction eff.)	LNG007	26.35
	Dairy and feedlot waste CNG	CNG004	30.13
Biodiesel	Soybean Biodiesel	BIOD001	22.73
	Tallow Biodiesel	BIOD008	32.83
	UCO Biodiesel	BIOD004	19.87
	Canola Biodiesel	BIOD006	35.73
	Corn Oil Biodiesel (from Wet DGS)	BIOD021	28.68
Renewable Diesel	Soybean RD	RNWD001	22.01
	Tallow RD	RNWD002	31.22
	UCO RD	--	18.21
	Canola RD	--	30.39
	Corn Oil RD (from Wet DGS)	--	28.49
Ethanol	Sugarcane Base Case; no credit	ETHS001	41.43
	Sugarcane; mechanized harvest and power export	ETHS002	31.09
	Sugarcane; mechanized harvest (harvest only)	--	32.17
	Sugarcane; power export only	ETHS003	40.35
	Sorghum Ethanol; 100% natural gas	ETHG001	67.29

[2] Direct values (without energy efficiency ratio adjustments). Source: California Air Resources Board, CA-GREET 1.8b versus 2.0 CI Comparison Table, April 1, 2015; http://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/040115_pathway_ci_comparison.pdf.

	Fuel	Pathway Identifier	Carbon Intensity Values (gCO_2e/MJ)
	Corn Ethanol; 100% natural gas	ETHC004	60.29
Hydrogen	Hydrogen Gas; compressed H_2 from central reforming of NG; liquefaction and re-gasification	HYGN001	151.01
	Hydrogen Gas; liquid H_2 from central reforming of NG	HYGN002	143.51
	Hydrogen Gas; compressed H_2 from central reforming of NG (no liquefaction and re-gasification steps)	HYGN003	105.65
	Hydrogen Gas; compressed H_2 from on-site reforming of NG	HYGN004	105.13
	Hydrogen Gas; compressed H_2 from on-site reforming with renewable feedstocks (2/3 NA-NG and 1/3 biomethane)	HYGN005	89.84
Electricity	Average California Electricity	ELC001	105.16
Anaerobic Digestion	Biomethane CNG derived from the high solids anaerobic digestion (HSAD) of food and green wastes	CNG005	-34.70
	Biomethane CNG from anaerobic digestion of wastewater sludge at a small-to-medium-sized wastewater treatment plant	CNG021	30.98
	Biomethane CNG from anaerobic digestion of wastewater sludge at a medium-to-large-sized wastewater treatment plant	CNG020	7.80

- Table MSF App D3: EER Values for Fuels Used in Light- Medium- and Heavy-Duty Applications[3]

Fuels Used as a Diesel Replacement for Heavy-Duty and Off-Road Applications	
Fuel/Vehicle Combinations	**EER Value Relative to Diesel**
Diesel Fuel or Biomass Based Diesel Blends	1.0
CNG or LNG/Any Vehicles (Spark-Ignition Engines)	0.9
CNG/LNG /Any Vehicle (Compression-Ignition Engines)	1.0
Electricity / Battery Electric or Plug-in Hybrid Electric Truck	2.7
Electricity / Fixed Guideway, Heavy Rail	4.6
Electricity / Fixed Guideway, Light Rail	3.3
Electricity / Trolley Bus, Cable Car, Street Car	3.1
Electricity/Forklifts or Equipment	3.8
H_2 / Fuel Cell Vehicle	1.9

[3] Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Proposed Re-Adoption of the Low Carbon Fuel Standard, December 2014 (http://www.arb.ca.gov/regact/2015/lcfs2015/lcfs15isor.pdf). For gasoline as a fuel replacement, see Table III-3, page III-22.

Cost-Effectiveness and Emission Reduction Formulas for Calculations of GHG Emissions[4]

A. Well-to-Wheel GHG Emission Calculations

Formula 1: Liquid / Natural Gas and Hydrogen Fueled Vehicles

$$GHG\ EF = carbon\ intensity * \frac{fuel\ energy\ density}{efficiency} * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

$$= \frac{gram\ CO2e}{MJ} * \left(\frac{MJ}{gal}\ or\ \frac{MJ}{kg}\ or\ \frac{MJ}{scf}\right) * \left(\frac{gal}{day}\ or\ \frac{kg}{day}\ or\ \frac{scf}{day}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

Where GHG EF is the Greenhouse Gas Emission Factor

Formula 2: Electric Vehicles

$$GHG\ EF = \frac{metric\ ton\ CO2e}{year} = carbon\ intensity * unit\ conversion * efficiency$$

$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{3.60\ MJ}{kWh}\right) * \left(\frac{X\ kWh}{year}\right) * \frac{1\ metric\ ton}{1{,}000{,}000\ grams}$$

B. Conversion from Diesel Fuel Usage to Electricity / Hydrogen / CNG Usage

Formula 3:

$$= \left(\frac{X\ gal\ Diesel}{yr}\right)\left(ED\ \frac{MJ}{1\ gal\ diesel}\right) * \left(ED\ \frac{NF\ unit}{MJ}\right) * \left(\frac{1}{EER}\right)$$

Where:
X is the number of gallons diesel fuel used as a basis for the conversion;
NF is the new fuel that is proposed to be used as a diesel replacement;
ED is the Energy Density of the replacement fuel (see Table MSF App D1: Fuel Energy Density); and
Unit is the units associated with the replacement fuel:

Electricity:	kWh
Hydrogen:	kg
CNG:	scf

[4] GHG emissions are measured in "CO_2 equivalent", which means the number of metric tons of CO_2 emissions with the same global warming potential as one metric ton of another greenhouse gas.

C. GHG Emission Reduction Calculation

Using the results from determining the GHG emissions that are associated with the base case and the advanced technology and taking their difference gives the estimated emission reductions that are associated with the proposed project.

Base case vehicles or equipment for the purpose of this solicitation are the cleanest vehicle or equipment that is commercially available at the time the application for funding is submitted.

Formula 4:

Project GHG ER_{annual} = GHG EF_{base} - GHG $EF_{adv\ tech}$

Where:

- GHG ER_{annual} is the annual GHG emission reductions that are associated with the proposed project.
- GHG EF_{base} is the GHG emission factor associated with the base case vehicle or equipment that the advanced technology vehicle or equipment is compared too.
- GHG $ER_{adv\ tech}$ is the GHG emission factor that is associated with the proposed technology.

D. Cost-Effectiveness Calculations for GHG

The cost-effectiveness of a project is determined by dividing the annualized cost of the potential project by the annual emission reductions that will be achieved by the project as shown in Formula 5 below.

Formula 5:

$$Cost\ Effectiveness\ \left(\frac{\$}{metric\ ton}\right) = \left(\frac{\frac{CRF * (\$Advanced\ Technology\ Vehicle - \$Baseline\ Diesel\ Vehicle)}{year}}{\left(\frac{metric\ ton\ emissions\ reduced}{year}\right)}\right)$$

For the purposes of this Solicitation:

Capital Recover Factor = CRF

CRF_2 = 0.515 per Moyer Table G-3b (2-year life)

CRF_{10} = 0.111 per Moyer Table G-3b (10-year life)

E. Composite Carbon Intensity Calculations

Formula 6 below is to use to determine a composite Carbon Intensity value for use in the calculations if two of the same fuel types are to be blended for use in the propose vehicle or equipment. Using values from Table MSF App D2: Fuel Carbon Intensity Values above as inputs:

Formula 6:

$$CI_{\text{composite}} = (Fraction\ of\ total\ fuel * (CI\ fuel\ 1)) + (fraction\ of\ total\ fuel * (CI\ Fuel\ 2))$$

Where CI is the Carbon Intensity of the fuel.

Cost-Effectiveness and Emission Reduction Calculations for Criteria Pollutant and Particulate Matter Emissions (from the Moyer Guidelines)

Only the relevant language from the Moyer Guidelines is included below. Language has been modified where necessary for the purposes of this Solicitation. Tables that contain emission factors and necessary inputs follow at the end of this section. Updates to the below tables may have been made since the release of this solicitation. Only use the information included in the below tables for criteria and toxic emission reduction and cost effectiveness calculations.

Baseline vehicles or equipment for the purpose of this solicitation are the cleanest vehicle or equipment that is commercially available at the time the application for funding is submitted.

1. **Calculating Cost-Effectiveness**

The cost-effectiveness of a project is determined by dividing the annualized cost of the potential project by the annual weighted surplus emission reductions that will be achieved by the project as shown in Formula C-1 below.

Formula C-1: Cost-Effectiveness of Weighted Surplus Emission Reductions ($/ton)

$$\textit{Cost-Effectiveness (\$/ton)} = \frac{\textit{Annualized Cost (\$/year(yr))}}{\textit{Annual Weighted Surplus Emission Reductions (tons/yr)}}$$

Descriptions on how to calculate annual emission reductions and annualized cost are provided in the following sections.

2. **Determining the Annualized Cost**

Annualized cost is the amortization of the one-time incentive grant amount for the life of the project to yield an estimated annual cost. The annualized cost is calculated by multiplying the incremental cost by the capital recovery factor (CRF) from Table G-3. [NOTE: For the purposes of this Solicitation, the CRF is 0.106, which assumes a 10-year life.] The resulting annualized cost is used to complete Formula C-1 above to determine the cost-effectiveness of surplus emission reductions.

Formula C-2: Annualized Cost ($)

*Annualized Cost = CRF * incremental cost ($)*

CRF_2 = 0.515 per Moyer Table G-3b (2 year life)
CRF_{10} = 0.111 per Moyer Table G-3b (10-year life)

3. Calculating the Incremental Cost

Formula C-3: Incremental Cost ($)

Incremental Cost = Cost of New Technology ($) – Cost of Baseline Diesel Technology ($)

4. Calculating the Annual Weighted Surplus Emission Reductions

Annual weighted emission reductions are estimated by taking the sum of the project's annual surplus pollutant reductions following Formula C-5 below. This will allow projects that reduce one, two, or all three of the covered pollutants to be evaluated.. While oxides of nitrogen (NOx) and reactive organic gases (ROG) emissions are given equal weight, emissions of particulate matter (PM) carry a greater weight in the calculation.

Formula C-5: Annual Weighted Surplus Emission Reductions (tons/yr)

Weighted Emission Reductions =

*NOx reductions (tons/yr) + ROG reductions (tons/yr) + [20 * (PM reductions (tons/yr)]*

The result of Formula C-5 is used to complete Formula C-1 to determine the cost-effectiveness of surplus emission reductions.

In order to determine the annual surplus emission reductions by pollutant, emission reduction calculations need to be completed for each pollutant (NOx, ROG, and PM), for the baseline technology and the reduced technology, totaling up to 4 calculations:

Baseline Technology	Reduced Technology
1. Annual emissions of NOx	4. Annual emissions of NOx
2. Annual emissions of ROG	5. Annual emissions of ROG
3. Annual emissions of PM	6. Annual emissions of PM

These calculations are completed for each pollutant by multiplying the engine emission factor or converted emission standard (found in Appendix D) by the annual activity level and by other adjustment factors as specified for the calculation methodologies presented.

5. Calculating Annual Emission Reductions Based on Usage

(A) Calculating Annual Emissions Based on Fuel Consumption

When annual fuel consumption is used for determining emission reductions, the equipment activity level must be based on annual fuel usage within California provided by the applicant.

A fuel consumption rate factor must be used to convert emissions given in g/bhp-hr to units of grams of emissions per gallon of fuel used (g/gal). The fuel consumption rate factor is a number that combines the effects of engine efficiency and the energy content of the fuel used in that engine into an approximation of the amount of work output by an engine for each unit of fuel consumed. The fuel consumption rate factor is found in Table D-24 later in this appendix. Formulas C-8 and C-9 below are the formulas for calculating annual emissions based on annual fuel consumed.

Formula C-8: Estimated Annual Emissions based on Fuel Consumed using Emission Factors or Converted Emission Standard (tons/yr)

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * fuel consumption rate factor (bhp-hr/gallon (gal)) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

Formula C-9: Estimated Annual Emissions based on Fuel using Emission Factors (tons/yr)

Annual Emission Reductions =

*Emission Factor (g/gal) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

(B) Calculating Annual Emissions Based on Annual Miles Traveled

Calculations based on annual miles traveled are used for on-road projects only.

<u>Calculations Using Emission Factors</u>: There is no conversion since the emission factors for on-road projects provided are given in units of g/mile. Formula C-10 describes the method for calculating pollutant emissions based on emission factors and miles traveled.

Formula C-10: Estimated Annual Emissions based on Mileage using Emission Factors (tons/yr)

Annual Emission Reductions =

*Emission Factor (g/mile) * Activity (miles/yr) * Percent Operation in CA * ton/907,200g*

<u>Calculating Annual Emissions Based on Converted Standards</u>: The unit conversion factors found in Tables D-5 and D-6 (Appendix D) are used to convert the units of the converted emission standard (g/bhp-hr) to g/mile. Formula C-11 describes the method for calculating pollutant emissions using converted emission standards.

Formula C-11: Estimated Annual Emissions based on Mileage using Converted Emission Standards (tons/yr)

Annual Emission Reductions =

*Converted Emission Standard (g/bhp-hr) * Unit Conversion (bhp-hr/mile) * Activity (miles/yr) * Percent Operation in CA * ton/907,200 g*

List of Criteria Pollutant Cost Effectiveness Formulas

For an easy reference, the necessary formulas to calculate the cost-effectiveness of surplus emission reductions for a project funded through the Carl Moyer Program are provided below.

<u>Formula C-1</u>: Cost-Effectiveness of Weighted Surplus Emission Reductions ($/ton):

$$\text{Cost-Effectiveness (\$/ton)} = \frac{\text{Annualized Cost (\$/year(yr))}}{\text{Annual Weighted Surplus Emission Reductions (tons/yr)}}$$

<u>Formula C-2</u>: Annualized Cost ($)

*Annualized Cost = 0.106 * incremental cost ($)*

<u>Formula C-3</u>: Incremental Cost ($)

Incremental Cost = Cost of New Technology ($) – Cost of Baseline Diesel Technology ($)

<u>Formula C-5</u>: Annual Weighted Surplus Emission Reductions

Weighted Emission Reductions =

*NOx reductions (tons/yr) + ROG reductions (tons/yr) + [20 * (PM reductions (tons/yr)]*

<u>Formula C-8</u>: Estimated Annual Emissions based on Fuel Consumed using Emission Factors or Converted Emission Standard (tons/yr)

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * fuel consumption rate factor (bhp-hr/gallon (gal)) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

Formula C-9: Estimated Annual Emissions based on Fuel using Emission Factors (tons/yr)

Annual Emission Reductions =

*Emission Factor (g/gal) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

Formula C-10: Estimated Annual Emissions based on Mileage using Emission Factors (tons/yr)

Annual Emission Reductions =

*Emission Factor (g/mile) * Activity (miles/yr) * Percent Operation in CA * ton/907,200g*

Formula C-11: Estimated Annual Emissions based on Mileage using Converted Emission Standards (tons/yr)

Annual Emission Reductions =

*Converted Emission Standard (g/bhp-hr) * Unit Conversion (bhp-hr/mile) * Activity (miles/yr) * Percent Operation in CA * ton/907,200g*

Tables for Calculating Criteria and Toxic Pollutant Emission Reductions

ON-ROAD TRUCK TABLES

Table D-1
Diesel Heavy-Duty Engines
Converted Emission Standards for Fuel Based Usage Calculations

EO Certification Standards g/bhp-hr		NOx	ROG[(a)]	PM10
		g/gal[(b)(c)(d)]		
6.0 NOx	0.60 PM10	103.23	5.33	7.992
5.0 NOx	0.25 PM10	86.03	4.44	3.330
5.0 NOx	0.10 PM10	86.03	4.44	1.332
4.0 NOx	0.10 PM10	68.82	3.55	1.332
2.5 NOx + NMHC	0.10 PM10	40.86	2.11	1.332
1.8 NOx + NMHC	0.01 PM10	29.42	1.52	0.148
1.5 NOx + NMHC	0.01 PM10	24.52	1.27	0.148
1.2 NOx + NMHC	0.01 PM10	19.61	1.01	0.148
0.84 NOx + NMHC	0.01 PM10	13.73	0.71	0.148
0.50 NOx	0.01 PM10	8.60	0.44	0.148
0.20 NOX	0.01 PM10	3.44	0.18	0.148

a - ROG = HC * 1.26639.
b - Fuel based emissions factors were calculated using fuel consumption rate factors from Table D-24.
c - Fuel based factors are for engines less than 750 horsepower only.
d - Emission standards were converted where appropriate, using the NMHC and NOx fraction default values and the ultra low-sulfur diesel fuel correction factors listed in Tables D-25 and D-26, respectively.

Table D-2
Alternative Fuel Heavy-Duty Engines
Converted Emission Standards for Fuel Based Usage Calculations

EO Certification Standards g/bhp-hr		NOx	ROG[(a)]	PM10
		g/gal[(b)(c)(d)]		
6.0 NOx	0.60 PM10	111.00	35.14	11.100
5.0 NOx	0.25 PM10	92.50	29.29	4.625
5.0 NOx	0.10 PM10	92.50	29.29	1.850
4.0 NOx	0.10 PM10	74.00	23.43	1.850
2.5 NOx + NMHC	0.10 PM10	37.00	11.71	1.850
1.8 NOx + NMHC	0.01 PM10	26.64	8.43	0.185
1.5 NOx + NMHC	0.01 PM10	22.20	7.03	0.185
1.2 NOx + NMHC	0.01 PM10	17.76	5.62	0.185
0.84 NOx + NMHC	0.01 PM10	12.43	3.94	0.185
0.50 NOx	0.01 PM10	9.25	2.93	0.185
0.20 NOX	0.01 PM10	3.70	1.17	0.185

a - ROG = HC * 1.26639.
b - Fuel based emissions factors were calculated using fuel consumption rate factors from Table D-24.
c - Fuel based factors are for engines less than 750 horsepower only.
d - Emission standards were converted where appropriate, using the NMHC and NOx fraction default values listed in Table D-25.

Table D-3
Heavy-Duty Vehicles
14,001-33,000 pounds (lbs) Gross Vehicle Weight Rating (GVWR)
Emission Factors for Mileage Based Calculations (g/mile)[(a)]

Model Year	Diesel[(b)]		
	NOx	ROG[(c)]	PM10
Pre-1987	14.52	0.75	0.69
1987-1990	14.31	0.59	0.75
1991-1993	10.70	0.26	0.41
1994-1997	10.51	0.20	0.23
1998-2002	10.33	0.20	0.25
2003-2006	6.84	0.13	0.16
2007-2009	4.01	0.11	0.02
2007-2009 (0.50 g/bhp-hr NOx or Cleaner)[(d)]	1.73	0.10	0.017
2010+	0.74	0.09	0.02

a - EMFAC 2011 Zero-Mile Based Emission Factors.

b - Emission factors incorporate the ultra low-sulfur diesel fuel correction factors listed in Table D-26.

c - ROG = HC * 1.26639.

d - Use interpolated values assuming 1.2 g/bhp-hr NOx Standards for 2007-2009 Model Year Grouping and 0.2 g/bhp-hr NOx Standards for 2010+ Model Years.

Table D-4
Heavy-Duty Vehicles
Over 33,000 lbs GVWR
Emission Factors for Mileage Based Calculations (g/mile)[a]

Model Year	Diesel[b]		
	NOx	ROG[c]	PM10
Pre-1987	21.37	1.09	1.25
1987-1990	21.07	0.86	1.35
1991-1993	18.24	0.56	0.56
1994-1997	17.92	0.42	0.37
1998-2002	17.61	0.43	0.40
2003-2006	11.64	0.27	0.25
2007-2009	6.62	0.23	0.03
2007-2009 (0.50 g/bhp-hr NOx or Cleaner)[d]	2.88	0.20	0.028
2010+	1.27	0.19	0.03

a - EMFAC 2011 Zero-Mile Based Emission Factors.
b - Emission factors incorporate the ultra low-sulfur diesel fuel correction factors listed in Table D-26.
c - ROG = HC * 1.26639.
d - Use interpolated values assuming 1.2 g/bhp-hr NOx Standards for 2007-2009 Model Year Grouping and 0.2 g/bhp-hr NOx Standards for 2010+ Model Years.

OFF-ROAD PROJECTS AND
NON-MOBILE AGRICULTURAL PROJECTS

Table D-10
Off-Road Diesel Engines Default Load Factors

Category	Equipment Type	Load Factor
Airport Ground Support	Aircraft Tug	0.54
	Air Conditioner	0.75
	Air Start Unit	0.90
	Baggage Tug	0.37
	Belt Loader	0.34
	Bobtail	0.37
	Cargo Loader	0.34
	Cargo Tractor	0.36
	Forklift	0.20
	Ground Power Unit	0.75
	Lift	0.34
	Passenger Stand	0.40
	Service Truck	0.20
	Other GSE	0.34
Agricultural (Mobile, Portable or Stationary)	Agricultural Mowers	0.43
	Agricultural Tractors	0.70
	Balers	0.58
	Combines/Choppers	0.70
	Chippers/Stump Grinders	0.73
	Generator Sets	0.74
	Hydro Power Units	0.48
	Irrigation Pump	0.65
	Shredders	0.40
	Sprayers	0.50
	Swathers	0.55
	Tillers	0.78
	Other Agricultural	0.51
Construction	Air Compressors	0.48
	Bore/Drill Rigs	0.50
	Cement & Mortar Mixers	0.56
	Concrete/Industrial Saws	0.73
	Concrete/Trash Pump	0.74
	Cranes	0.29
	Crawler Tractors	0.43
	Crushing/Process Equipment	0.78
	Excavators	0.38
	Graders	0.41

Table D-10
Off-Road Diesel Engines Default Load Factors
(Continued)

Category	Equipment Type	Load Factor
Construction	Off-Highway Tractors	0.44
	Off-Highway Trucks	0.38
	Pavers	0.42
	Other Paving	0.36
	Pressure Washer	0.30
	Rollers	0.38
	Rough Terrain Forklifts	0.40
	Rubber Tired Dozers	0.40
	Rubber Tired Loaders	0.36
	Scrapers	0.48
	Signal Boards	0.78
	Skid Steer Loaders	0.37
	Surfacing Equipment	0.30
	Tractors/Loaders/Backhoes	0.37
	Trenchers	0.50
	Welders	0.45
	Other Construction Equipment	0.42
Industrial	Aerial Lifts	0.31
	Forklifts	0.20
	Sweepers/Scrubbers	0.46
	Other General Industrial	0.34
	Other Material Handling	0.40
Logging	Fellers/Bunchers	0.71
	Skidders	0.74
Oil Drilling	Drill Rig	0.50
	Lift (Drilling)	0.60
	Swivel	0.60
	Workover Rig (Mobile)	0.50
	Other Workover Equipment	0.60
Cargo Handling	Container Handling Equipment	0.59
	Cranes	0.43
	Excavators	0.57
	Forklifts	0.30
	Other Cargo Handling Equipment	0.51
	Sweeper/Scrubber	0.68
	Tractors/Loaders/Backhoes	0.55
	Yard Trucks	0.65
Other	All	0.43

Table D-11
Uncontrolled Off-Road Diesel Engines
Emission Factors (g/bhp-hr)

Horsepower	Model Year	NOx	ROG	PM10
25 – 49	pre-1988	6.51	2.21	0.547
	1988 +	6.42	2.17	0.547
50 – 119	pre-1988	12.09	1.73	0.605
	1988 +	8.14	1.19	0.497
120+	pre-1970	13.02	1.59	0.554
	1970 – 1979	11.16	1.20	0.396
	1980 – 1987	10.23	1.06	0.396
	1988 +	7.60	0.82	0.274

Table D-12
Controlled Off-Road Diesel Engines
Emission Factors (g/bhp-hr)[a]

Horsepower	Tier	NOx	ROG	PM10
25-49	1	5.26	1.74	0.480
	2	4.63	0.29	0.280
	4 Interim	4.55	0.12	0.128
	4 Final	2.75	0.12	0.008
50-74	1	6.54	1.19	0.552
	2	4.75	0.23	0.192
	3[b]	2.74	0.12	0.192
	4 Interim	2.74	0.12	0.112
	4 Final	2.74	0.12	0.008
75-99	1	6.54	1.19	0.552
	2	4.75	0.23	0.192
	3	2.74	0.12	0.192
	4 Phase-Out	2.74	0.12	0.008
	4 Phase-In/ Alternate NOx	2.14	0.11	0.008
	4 Final	0.26	0.06	0.008
100-174	1	6.54	0.82	0.274
	2	4.17	0.19	0.128
	3	2.32	0.12	0.112
	4 Phase-Out	2.32	0.12	0.008
	4 Phase-In/ Alternate NOx	2.15	0.06	0.008
	4 Final	0.26	0.06	0.008
175-299	1	5.93	0.38	0.108
	2	4.15	0.12	0.088
	3	2.32	0.12	0.088
	4 Phase-Out	2.32	0.12	0.008
	4 Phase-In/ Alternate NOx	1.29	0.08	0.008
	4 Final	0.26	0.06	0.008

Table D-12
Controlled Off-Road Diesel Engines
Emission Factors (g/bhp-hr)[(a)]
(Continued)

Horsepower	Tier	NOx	ROG	PM10
300-750	1	5.93	0.38	0.108
	2	3.79	0.12	0.088
	3	2.32	0.12	0.088
	4 Phase-Out	2.32	0.12	0.008
	4 Phase-In/ Alternate NOx	1.29	0.08	0.008
	4 Final	0.26	0.06	0.008
751+	1	5.93	0.38	0.108
	2	3.79	0.12	0.088
	4 Interim	2.24	0.12	0.048
	4 Final	2.24	0.06	0.016

Note: Engines that are participating in the "Tier 4 Early Introduction Incentive for Engine Manufacturers" program per California Code of Regulations, Title 13, section 2423(b)(6) are eligible for funding provided the engines are certified to the final Tier 4 emission standards. The ARB Executive Order indicates engines certified under this provision. The emission rates for these engines used to determine cost-effectiveness shall be equivalent to the emission factors associated with Tier 3 engines.

For equipment with baseline engines certified under the flexibility provisions per California Code of Regulations, Title 13, section 2423(d), baseline emission rates shall be determined by using the previous applicable emission standard or Tier for that engine model year and horsepower rating. The ARB Executive Order indicates engines certified under this provision.

a - Emission factors were converted using the ultra low-sulfur diesel fuel correction factors listed in Table D-27.
b - Alternate compliance option.

LARGE SPARK IGNITION ENGINES

Table D-13
Off-Road LSI Equipment Default Load Factors

Category	Equipment Type	Load Factor
Agriculture (Mobile, Portable or Stationary)	Agricultural Tractors	0.62
	Balers	0.55
	Combines/Choppers	0.74
	Chipper/Stump Grinder	0.78
	Generator Sets	0.68
	Sprayers	0.50
	Swathers	0.52
	Pumps	0.65
	Other Agricultural Equipment	0.55
Airport Ground Support	A/C Tug	0.80
	Baggage Tug	0.55
	Belt Loader	0.50
	Bobtail	0.55
	Cargo Loader	0.50
	Forklift	0.30
	Ground Power Unit	0.75
	Lift	0.50
	Passenger Stand	0.59
	Other GSE	0.50
Construction	Air Compressors	0.56
	Asphalt Pavers	0.66
	Bore/Drill Rigs	0.79
	Concrete/Industrial Saws	0.78
	Concrete/Trash Pump	0.69
	Cranes	0.47
	Gas Compressor	0.85
	Paving Equipment	0.59
	Pressure Washer	0.85
	Rollers	0.62
	Rough Terrain Forklifts	0.63
	Rubber Tired Loaders	0.54
	Skid Steer Loaders	0.58
	Tractors/Loaders/Backhoes	0.48

Table D-13
Off-Road LSI Equipment Default Load Factors
(Continued)

Category	Equipment Type	Load Factor
Construction	Trenchers	0.66
	Welders	0.51
	Other Construction	0.48
Industrial	Aerial Lifts	0.46
	Forklifts	0.30
	Sweepers/Scrubbers	0.71
	Other Industrial	0.54

Table D-14
Off-Road LSI Engines
Emission Factors (g/bhp-hr)

Horsepower	Fuel	Model Year	NOx	ROG	PM10
25 – 49	Gasoline	Uncontrolled – pre-2004	8.01	3.81	0.060
		Controlled 2001-2006	1.33	0.72	0.060
		Controlled 2007-2009[(a)]	0.89	0.48	0.060
		Controlled 2010+	0.27	0.14	0.060
	Alt Fuel	Uncontrolled – pre-2004	13.00	0.90	0.060
		Controlled 2001-2006	1.95	0.09	0.060
		Controlled 2007-2009[(a)]	1.30	0.06	0.060
		Controlled 2010+	0.39	0.02	0.060
50 – 120	Gasoline	Uncontrolled – pre-2004	11.84	2.66	0.060
		Controlled 2001-2006	1.78	0.26	0.060
		Controlled 2007-2009[(a)]	1.19	0.18	0.060
		Controlled 2010+	0.36	0.05	0.060
	Alt Fuel	Uncontrolled – pre-2004	10.51	1.02	0.060
		Controlled 2001-2006	1.58	0.11	0.060
		Controlled 2007-2009[(a)]	1.05	0.07	0.060
		Controlled 2010+	0.32	0.02	0.060
>120	Gasoline	Uncontrolled – pre-2004	12.94	1.63	0.060
		Controlled 2001-2006	1.94	0.16	0.060
		Controlled 2007-2009[(a)]	1.29	0.11	0.060
		Controlled 2010+	0.39	0.03	0.060
	Alt Fuel	Uncontrolled – pre-2004	10.51	0.90	0.060
		Controlled 2001-2006	1.58	0.09	0.060
		Controlled 2007-2009[(a)]	1.05	0.06	0.060
		Controlled 2010+	0.32	0.02	0.060

a - Emission factors for federally certified engines used in preempt equipment.

Table D-15
Emission Factors for Off-Road LSI Engine Retrofits
Verified to Absolute Emission Number (g/bhp-hr)

Manufacturers of LSI retrofit systems may verify to a percent emission reduction or absolute emissions. If a retrofit system is verified to a percent reduction, the emission factors will be that verified percent of the appropriate emissions factors in Table D-14. If a retrofit system is verified to an absolute emission number, use the following table for the emission factors.

Fuel	Verified Value	NOx	ROG	PM10
Gasoline	3.0 g/bhp-hr	1.78	0.26	0.060
	2.5 g/bhp-hr	1.48	0.22	0.060
	2.0 g/bhp-hr	1.19	0.18	0.060
	1.5 g/bhp-hr	0.89	0.13	0.060
	1.0 g/bhp-hr	0.59	0.09	0.060
	0.6 g/bhp-hr	0.36	0.05	0.060
	0.5 g/bhp-hr	0.30	0.04	0.060
Alt Fuel	3.0 g/bhp-hr	1.58	0.10	0.060
	2.5 g/bhp-hr	1.32	0.09	0.060
	2.0 g/bhp-hr	1.05	0.07	0.060
	1.5 g/bhp-hr	0.79	0.05	0.060
	1.0 g/bhp-hr	0.53	0.03	0.060
	0.6 g/bhp-hr	0.32	0.02	0.060
	0.5 g/bhp-hr	0.26	0.02	0.060

Table D-16
Off-Road LSI Engines Certified to Optional Standards
Emission Factors (g/bhp-hr)

Horsepower	Fuel	Optional Standard	NOx	ROG	PM10
25-50	Gasoline	1.50	0.67	0.36	0.060
		1.00	0.44	0.24	0.060
		0.60	0.27	0.14	0.060
		0.40	0.18	0.10	0.060
		0.20	0.09	0.05	0.060
		0.10	0.04	0.02	0.060
	Alt Fuel	1.50	0.98	0.05	0.060
		1.00	0.65	0.03	0.060
		0.60	0.39	0.02	0.060
		0.40	0.26	0.01	0.060
		0.20	0.13	0.01	0.060
		0.10	0.07	0.00	0.060
50-120	Gasoline	1.50	0.89	0.13	0.060
		1.00	0.59	0.09	0.060
		0.60	0.36	0.05	0.060
		0.40	0.24	0.04	0.060
		0.20	0.12	0.02	0.060
		0.10	0.06	0.01	0.060
	Alt Fuel	1.50	0.79	0.05	0.060
		1.00	0.53	0.03	0.060
		0.60	0.32	0.02	0.060
		0.40	0.21	0.01	0.060
		0.20	0.11	0.01	0.060
		0.10	0.05	0.00	0.060
>120	Gasoline	1.50	0.97	0.08	0.060
		1.00	0.65	0.05	0.060
		0.60	0.39	0.03	0.060
		0.40	0.26	0.02	0.060
		0.20	0.13	0.01	0.060
		0.10	0.06	0.01	0.060
	Alt Fuel	1.50	0.79	0.05	0.060
		1.00	0.53	0.03	0.060
		0.60	0.32	0.02	0.060
		0.40	0.21	0.01	0.060
		0.20	0.11	0.01	0.060
		0.10	0.05	0.00	0.060

LOCOMOTIVES

Table D-17a
Locomotive Emission Factors (g/bhp-hr)
Based on 1998 Federal Standards

Engine Model Year	Type	NOx[(a)]	ROG[(b)]	PM10[(a)]
Pre-1973	Line-haul and Passenger	12.22	0.51	0.275
	Switcher	16.36	1.06	0.378
1973-2001 Tier 0	Line-haul and Passenger	8.93	1.05	0.516
	Switcher	13.16	2.21	0.619
2002-2004 Tier 1	Line-haul and Passenger	6.96	0.58	0.387
	Switcher	10.34	1.26	0.464
2005-2011 Tier 2	Line-haul and Passenger	5.17	0.32	0.172
	Switcher	7.61	0.63	0.206

These factors are to be used for the project baseline emissions if the baseline locomotive is certified or required to be certified to the 1998 federal locomotive remanufacture standards, and for the reduced emission locomotive if the project locomotive is remanufactured to these 1998 standards. Factors are based upon Regulatory Impact Analysis: Final United States Environmental Protection Agency (U.S. EPA) Locomotive Regulation (2008).
a - NOx and PM10 emission factors have been adjusted by a factor of 0.94 and 0.86, respectively, to account for use of California ultra-low sulfur diesel fuel.
b - ROG = HC * 1.053

Table D-17b
Locomotive Emission Factors (g/bhp-hr)
Based on 2008 Federal Standards

Engine Model Year	Type	NOx[(a)]	ROG[(b)]	PM10[(a)]
1973-2001 Tier 0+	Line-haul and Passenger	6.96	0.58	0.189
	Switcher	11.09	2.21	0.224
2002-2004 Tier 1+	Line-haul and Passenger	6.96	0.58	0.189
	Switcher	10.34	1.26	0.224
2005-2011 Tier 2+	Line-haul and Passenger	5.17	0.32	0.086
	Switcher	7.61	0.63	0.112
2011-2014 Tier 3	Line-haul and Passenger	5.17	0.32	0.086
	Switcher	4.70	0.63	0.086
2015 Tier 4	Line-haul and Passenger	1.22	0.15	0.026
	Switcher	1.22	0.15	0.026

These factors are to be used for the project baseline emissions if the baseline locomotive is certified or required to be certified to the new (2008) federal locomotive remanufacture standards, and for the reduced emission locomotive if the project locomotive is remanufactured to the new standards or meets Tier 3 standards. Factors are based upon Regulatory Impact Analysis: Final U.S. EPA Locomotive Regulation (2008).
a - NOx and PM10 emission factors have been adjusted by a factor of 0.94 and 0.86, respectively, to account for use of California ultra-low sulfur diesel fuel.
b - ROG = HC * 1.053

Table D-18
Locomotive Idle-Limiting Device Emission Reduction Factors

Type	Factor
Switchers	0.90
Line-Haul	0.97
Passenger	0.97

Note: Factors based on assumption Idle Limiting Device (ILD) reduces locomotive engine idling by 50 percent. Multiply total baseline emissions by this factor to determine reduced emissions with ILD.

Table D-19a
Uncontrolled Harbor Craft Propulsion Engine
Emission Factors (g/bhp-hr)

Horsepower	Model Year	NOx	ROG	PM10
25-50	All	7.57	1.32	0.520
51-120	pre-1997	14.27	1.04	0.575
	1997+	9.70	0.71	0.524
121-250	pre-1971	15.36	0.95	0.527
	1971-1978	14.27	0.79	0.451
	1979-1983	13.17	0.72	0.376
	1984+	12.07	0.68	0.376
251+	pre-1971	15.36	0.91	0.506
	1971-1978	14.27	0.76	0.431
	1979-1983	13.17	0.68	0.363
	1984-1994	12.07	0.65	0.363
251-750	1995+	8.97	0.49	0.260
751+	1995+	12.07	0.60	0.363

Table D-19b
Controlled Harbor Craft Propulsion Engine
Emission Factors (g/bhp-hr)

Horsepower	Tier	NOx	ROG	PM10
25-50	1	6.93	1.30	0.580
	2	5.04	1.30	0.240
	3	5.04	1.30	0.176
51-120	1	6.93	0.71	0.524
	2	5.04	0.71	0.240
	3	5.04	0.71	0.176
121-175	1	8.97	0.49	0.290
	2	4.84	0.49	0.176
	3	3.60	0.49	0.077
176-750	1	8.97	0.49	0.290
	2	4.84	0.49	0.120
	3	3.87	0.49	0.068
751-1900	1	8.97	0.49	0.290
	2	5.24	0.49	0.160
	3	3.87	0.49	0.068
1901 +	1	8.97	0.49	0.290
	2	5.24	0.49	0.160
	3	4.14	0.49	0.085

Table D-20a
Uncontrolled Harbor Craft Auxiliary Engine
Emission Factors (g/bhp-hr)

Horsepower	Model Year	NOx	ROG	PM10
25-50	all	6.42	1.58	0.460
51-120	pre-1997	12.09	1.23	0.508
	1997+	8.14	0.85	0.417
121-250	pre-1971	13.02	1.13	0.466
	1971-1978	12.09	0.94	0.399
	1979-1983	11.16	0.86	0.333
	1984-1995	10.23	0.82	0.333
	1996+	7.75	0.59	0.255
251-750	pre-1971	13.02	1.08	0.448
	1971-1978	12.09	0.90	0.381
	1979-1983	11.16	0.81	0.321
	1984-1994	10.23	0.77	0.321
	1995+	7.60	0.58	0.230
751 +	pre-1971	13.02	1.08	0.448
	1971-1978	12.09	0.90	0.381
	1979-1986	11.16	0.81	0.321
	1987-1998	10.23	0.72	0.321
	1999+	7.75	0.58	0.255

Table D-20b
Controlled Harbor Craft Auxiliary Engine
Emission Factors (g/bhp-hr)

Horsepower	Tier	NOx	ROG	PM10
25-50	1	6.54	1.54	0.511
	2	5.04	1.54	0.240
	3	5.04	1.54	0.176
51-120	1	6.93	0.85	0.464
	2	5.04	0.85	0.240
	3	5.04	0.85	0.176
121-175	1	6.93	0.58	0.255
	2	4.84	0.58	0.176
	3	3.60	0.58	0.077
176-750	1	6.93	0.58	0.255
	2	4.84	0.58	0.120
	3	3.78	0.58	0.068
751-1900	1	6.93	0.58	0.255
	2	5.24	0.58	0.160
	3	3.87	0.58	0.068
1901 +	1	6.93	0.58	0.255
	2	5.24	0.58	0.160
	3	4.14	0.58	0.085

Table D-21
Harbor Craft Load Factors

Vessel Type	Propulsion Engine	Auxiliary Engine
Charter Fishing	0.52	0.43
Commercial Fishing	0.27	
Ferry/Excursion	0.42	
Pilot	0.51	
Tow	0.68	
Work	0.45	
Other	0.52	
Barge/Dredge	0.45	0.65
Crew & Supply	0.38	0.32
Tug	0.50	0.31

Table D-22
Shore Power
Default Emission Rates (Grams per kilowatt-hour (g/kWh))

Pollutant	Emission Rate
NOx	13.9
ROG	0.49
PM10 (marine gas oil fuel with 0.11- 0.5 % sulfur content)	0.38
PM10 (marine gas oil fuel with <= 0.10 % sulfur content)	0.25

Table D-23
Shore Power
Default Power Requirements

Ship Category	Ship Size / Type Default (Twenty-foot Equivalent Unit (TEU))	Power Requirement (kW)
Container Vessel	<1,000	1,000
	1,000 – 1,999	1,300
	2,000 – 2,999	1,600
	3,000 – 3,999	1,900
	4,000 – 4,999	2,200
	5,000 – 5,999	2,300
	6,000 – 6,999	2,500
	7,000 – 7,999	2,900
	8,000 – 9,999	3,300
	10,000 – 12,000	3,700
Passenger Vessel	No Default Value – Use Actual Power Requirement[a]	
Reefer	Break Bulk	1,300
	Fully containerized	3,300

a - The average power requirement for passenger vessels is 7,400 kW (ARB Oceangoing Vessel Survey, 2005).

ALL ENGINES

Table D-24
Fuel Consumption Rate Factors (bhp-hr/gal)

Category	Horsepower/Application	Fuel Consumption Rate
Non-Mobile Agricultural Engines	ALL	17.5
Locomotive	Line Haul and Passenger (Class I/II)	20.8
	Line Haul and Passenger (Class III)	18.2
	Switcher	15.2
Other	< 750 hp	18.5
	$\geq$ 750 hp	20.8

Example Calculations

Example Calculations are provided to illustrate all the permutations that staff expects may be included in an application for funding. Example calculations are included for four scenarios providing the values that are needed for a complete application, those required values are:

- GHG annual emission reductions from each proposed vehicle or piece of equipment
- Criteria pollutant and toxic air contaminant annual pollutant emissions reductions for each propose vehicle
- GHG cost effectiveness for a two year life during the time of the proposed project field demonstration
- GHG cost effectiveness for a 10 year life, two years after the end of the proposed demonstration project, assuming the technology is commercialized and available in the marketplace.
- Criteria pollutant and toxic air contaminant cost effectiveness for a two year life during the time of the proposed project field demonstration
- Criteria pollutant and toxic air contaminant cost effectiveness for a 10 year life, two years after the end of the proposed demonstration project, assuming the technology is commercialized and available to the marketplace.

GHG emission reductions are calculated in a well-to-wheel format and the criteria and toxic air contaminant pollutant emission reductions calculations are determined under a tank-to-wheel scenario. The example calculations contained in this appendix are illustrations of:

1. **Fuel Cell Yard Truck**
    - This example demonstrates a project that proposes to utilize a hydrogen fuel cell propulsion system in a yard truck application. The hydrogen refueling system that will be used for the demonstration is considered part of the match for the project and therefore does not need to comply with SB 1505 requirements, which call for 1/3 of hydrogen to be from renewable sources.

2. **Fuel Cell Transportation Refrigeration Unit:**
    - This example shows a project that proposes to utilize a hydrogen fuel cell as the power source for a transportation refrigeration unit. The hydrogen refueling station is proposed to be funded by the AQIP/GGRF grant and therefore must utilize renewable hydrogen as required by SB 1505.

3. **Battery-Electric Heavy Lift Forklift:**
    - This example shows a project that proposes to use grid power to recharge on-board battery packs contained in a heavy-lift forklift.

4. **Range Extending Battery-Dominant Regional Haul Truck**
    - This example shows the use of an internal combustion engine being used as a range extender for a battery-dominant on-road truck. The truck will use both grid charging and on-board natural gas for the range extending engine. The natural gas in this example will have a 15% renewable content.

All of the following examples use diesel fuel usage of the baseline vehicle or equipment as a basis for the GHG and criteria pollutant emission calculations. This technique may not adequately capture the emission profiles of all proposed applications however; this technique is used to allow all submitted applications to be scored on a level playing field.

If a proposed project is for an application that uses a baseline diesel engine of 24 hp or lower, for the purpose of this solicitation and to calculate the needed emission reductions and cost effectiveness, use the relevant Carl Moyer tables for a 25 hp baseline diesel engine.

Example 1: Use of hydrogen fuel cell in a yard truck application

Potential GHG emission reductions are determined on a well-to-wheel basis, while criteria pollutant emission reductions are determined using a tank-to-wheel analysis. This example assumes that a fuel cell yard truck will have the same energy requirements as a diesel counterpart and will be used the same number of hours. Further, it is assumed that this project will use hydrogen that is produced from natural gas and compressed for use in the project.

Baseline vehicle:

- 2010 diesel fueled yard truck with 2010 on-road engine
- Usage 1.6 gal per hour, 1500 hours of operation a year
- Yard truck cost at demonstration: $100,000
- Yard truck cost two years after demonstration: $100,000

Advanced Technology:

- Hydrogen Fuel Cell Yard Truck
- Yard truck cost at demonstration: $750,000
- Yard truck cost two years after demonstration: $500,000

Variables Used in Calculation:

Carbon Intensity

From Table MSF App D2: Fuel Carbon Intensity Values

CI = Carbon Intensity

$CI_{diesel} = \frac{102.76\ g\ CO2e}{MJ}$ Table Pathway Identifier ULSD001

From Table MSF App D2: Fuel Carbon Intensity Values

$CI_{hydrogen} = \frac{105.65\ g\ CO2e}{MJ}$ Pathway Identifier HYGN003

Energy Density

From Table MSF App D1: Fuel Energy Density

ED = Energy Density

$ED_{diesel} = \frac{134.47\ MJ}{gal\ diesel}$ $ED_{hydrogen} = \frac{120.00\ MJ}{kg\ H2}$

Energy Efficiency Ratio

From Table MSF App D3: EER Values for Fuels Used in Light- Medium- and Heavy-Duty Applications

EER = Energy Efficiency Ratio (unit less)

$EER_{hydrogen}$ = 1.9

Step 1: Calculate the baseline yard trucks annual fuel usage:

$$\frac{gal\ diesel}{year} = \left(\frac{1.6\ gallons}{hour}\right) * \left(\frac{1500\ hours}{year}\right) = \frac{2400\ gallons\ diesel}{year}$$

Step 2: Convert the diesel used per year from the baseline yard truck to the amount of hydrogen needed to do the same work. Using Formula 3 and the variable identified above.

Formula 3:

$$= \left(\frac{X\ gal\ Diesel}{yr}\right) * \left(ED\ \frac{MJ}{1\ gal\ diesel}\right) * \left(ED\ \frac{NF\ unit}{MJ}\right) * \left(\frac{1}{EER}\right)$$

Where:
X is the number of gallons diesel fuel used annually as a basis for the conversion;
NF is the new fuel that is proposed to be used as a diesel replacement;
ED is the Energy Density of the replacement fuel see Table MSF App D1: Fuel Energy Density; and
Unit is the units associated with the replacement fuel:

Electricity: kWh
Hydrogen: kg
CNG: scf

$$\frac{kg\ H2}{year} = \left(\frac{2400 gal\ diesel}{year}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{1\ kg\ H2}{120.00\ MJ}\right) * \left(\frac{1}{1.9}\right) = 1415\ \frac{kg\ H2}{year}$$

Step 3: Determine the GHG emissions that are attributed to the base case yard truck. Using Formula 1 and the variables identified above.

Formula 1:

$$GHG\ EF = carbon\ intensity * \frac{fuel\ energy\ density}{efficiency} * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

$$= (\frac{gram\ CO2e}{MJ}) * \left(\frac{MJ}{gal}\ or\ \frac{MJ}{kg}\ or\ \frac{MJ}{scf}\right) * \left(\frac{gal}{day}\ or\ \frac{kg}{day}\ or\ \frac{scf}{day}\right) * (\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams})$$

GHG EF_{base} $=\left(\frac{102.76\ g\ CO2e}{MJ}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{2400\ gal}{year}\right) * \left(\frac{1\ metric\ ton}{1{,}000{,}000\ grams}\right) = 33\ \frac{metric\ tons\ CO2e}{year}$

Step 4: Determine the GHG emissions that are attributed to the advanced technology fuel cell yard truck. Using the result from Step 2, the variables identified above as inputs into Formula 1.

GHG $EF_{adv\ tech}$ $=\left(\frac{105.65\ g\ CO2e}{MJ}\right) * \left(\frac{120.00\ MJ}{kg\ H2}\right) * \left(\frac{1415\ kg\ H2}{year}\right) * \left(\frac{1\ metric\ ton}{1{,}000{,}000\ grams}\right) = 18\ \frac{metric\ tons\ CO2e}{year}$

Step 5: Determine the annual GHG emission reductions that are associated with the proposed project. Using Formula 4 above populated by results from Step 3 and Step 4 from the above example to give the annual GHG emission benefit from the proposed project.

Formula 4:

Project GHG ER_{annual} = GHG EF_{base} - GHG $EF_{adv\ tech}$

Project GHG ER $_{annual}$ = $(\frac{33\ metric\ tons\ CO2e}{year}) - \left(\frac{18\ metric\ tons\ CO2e}{year}\right) = 15\ \frac{metric\ tons\ CO2e}{year}$

Step 6: Determine the annual criteria and toxic pollutant emission reductions that are associated with the proposed project. Since the base case diesel yard truck is using a 2010 on-road engine, inputs from Table D-1 and the result of Step1 above will be used to populate Formula C-9. There are not any tank-to-wheel criteria or toxic emissions associated with the use of the advanced technology yard truck, therefore all the emissions associated with the base case diesel yard truck are considered to be the criteria and toxic emission reductions for the proposed project.

For a 2010 on-road engine with Certification Standard of 0.20 g NOx/bhp-hr, Table D-1 gives emissions per gallon of diesel consumed. Therefore:

NOx = 3.44 $\frac{g\ NOx}{gal\ diesel}$; ROG =0.18 $\frac{g\ ROG}{gal\ diesel}$; PM10 = 0.148 $\frac{g\ PM\ 10}{gal}$

Using Formula C-9:

Formula C-9: Estimated Annual Emissions based on Fuel using Emission Factors (tons/yr). All the emission reductions are taking place in CA.

Annual Emission Reductions =

*Emission Factor (g/gal) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

Annual ER is the calculated annual emission reductions

Annual ER_{NOx} = $\left(\frac{3.44\ g\ NOx}{gal\ diesel}\right) * \left(\frac{2400 gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.0091\,\frac{tons\ NOx}{year}$

Annual ER_{ROG} = $(\frac{0.18\ g\ ROG}{gal\ diesel}) * \left(\frac{2400\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.00048\ \frac{tons\ ROG}{year}$

Annual ER_{PM10} = $\left(\frac{0.148\ g\ PM}{gal\ diesel}\right) * \left(\frac{2400 gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.00039\,\frac{tons\ PM}{year}$

Step 7: Determine the weighted annual surplus emission reductions that are associated with the proposed project. Using the results from Step 6 above along with the realization that the proposed fuel cell yard truck will not produce any criteria pollutant emissions in a tank-to-wheel scenario populate Formula C-5.

Formula C-5: Annual Weighted Surplus Emission Reductions (tons/yr)

Weighted Emission Reductions =

*NOx reductions (tons/yr) + ROG reductions (tons/yr) + [20 * (PM reductions (tons/yr)]*

Therefore using the results from Step 6 above and Formula C-5:

WER is the Weighted Emission Reductions

WER = $(0.0091\,\frac{tons\ NOx}{year}) + \left(\ 0.00048\ \frac{tons\ ROG}{year}\right) + 20 * \left(0.00039\,\frac{tons\ PM}{year}\right) = 0.017\,\frac{tons}{year}$

Therefore, WER = 0.0017 $\frac{tons\ criteria\ pollutants\ reduced}{year}$

Step 8: Determine the incremental cost of the proposed technology using Formula C-3 and the vehicle costs for the base case yard truck and the fuel cell yard truck given at the start of this example. Cost effectiveness is to be calculated for two scenarios; for two years during the demonstration and for 10 years, two years after the completion of the demonstration project.

Baseline vehicle:

- Yard truck cost at demonstration: $100,000
- Yard truck Cost two years after demonstration: $100,000

Advanced Technology:

- Yard truck cost at demonstration: $750,000
- Yard truck cost two years after demonstration: $500,000

Formula C-3: Incremental Cost ($)

Incremental Cost = Cost of New Technology ($) – Cost of Baseline Diesel Technology ($)

Incremental $\text{Cost}_{\text{2 years}}$ = $750,000 - $100,000 = $650,000

Incremental $\text{Cost}_{\text{10 years}}$ = $500,000 - $100,000 = $400,000

Step 9: Determine the GHG emission reduction cost effectiveness for the proposed project using the results from Step 5, Step 8 and Formula 5.

Formula 5:

Where CRF is the Capital Recover Factor

$$Cost\ Effectiveness\ (\frac{\$}{metric\ ton}) = \left(\frac{\frac{CRF * (\$Advanced\ Technology\ Vehicle - \$Baseline\ Diesel\ Vehicle}{year})}{(\frac{metric\ ton\ emissions\ reduced}{year})} \right)$$

For the purposes of this Solicitation:

CRF_2 = 0.515 per Moyer Table G-3b (2-year life)

CRF_{10} = 0.111 per Moyer Table G-3b (10-year life)

Therefore:

GHG C/E is the GHG Cost Effectiveness

$$\text{GHG C/E}_{\text{2 years}} = \left(\frac{\frac{(0.515*\$650,000)}{year}}{\frac{15\ metric\ tons\ CO2e}{year}}\right) = \frac{\$22,317}{metric\ ton\ CO2e\ reduced}$$

GHG C/E $_{10\ years}$ = $\left(\frac{\left(\frac{(0.111*\$400{,}000)}{year}\right)}{\frac{15\ metric\ tons\ CO2e}{year}}\right) = \frac{\$2{,}960}{metric\ tons\ CO2e\ reduced}$

Step 10: Determine the criteria pollutant cost effectiveness for the proposed technology. Use the results from Step 7 and Step 8 to populate Formula C-1.

Formula C-1: Cost-Effectiveness of Weighted Surplus Emission Reductions ($/ton)

Cost-Effectiveness ($/ton) = $\frac{\textit{Annualized Cost (\$/year(yr))}}{\textit{Annual Weighted Surplus Emission Reductions (tons/yr)}}$

Where C/E is cost effectiveness

CRF_2 = 0.515 per Moyer Table G-3b (2-year life)

CRF_{10} = 0.111 per Moyer Table G-3b (10-year life)

Criteria Pollutant C/E$_{2\ years}$ = $\left(\frac{\frac{(0.515*\$650{,}000)}{year}}{\frac{0.017\ tons\ WER}{year}}\right) = \frac{\$20\ million}{ton\ criteria\ pollutants\ reduced}$

Criteria Pollutant C/E$_{10\ years}$ = $\left(\frac{\frac{(0.111*\$400{,}000)}{year}}{\frac{0.017\ tons\ WER}{year}}\right) = \frac{\$2.6\ million}{ton\ criteria\ pollutants\ reduced}$

Example 2: Fuel Cell Transportation Refrigeration Unit (TRU)

Potential GHG emission reductions are determined on a well-to-wheel basis, while criteria pollutant emission reductions are determined using a tank-to-wheel analysis. This example assumes that a TRU will have the same energy requirements as a diesel counterpart and will be used the same number of hours. The initial chill down of the trailer, TRU operations and any needed standby power are provided by the fuel cell. Further, it is assumed that this project will use hydrogen that is SB 1505 compliant and therefore has a 1/3 renewable component.

Baseline TRU:

- Off-Road diesel engine: Tier-4 final certification, 24 hp
- Diesel usage: 0.8 gal per hour, 40 hours per week, 1664 gal per year
- TRU cost at demonstration: $26,000
- TRU cost two years after demonstration: $26,000

Advanced Technology:

- Hydrogen fuel cell TRU
- TRU cost at demonstration: $45,000
- TRU cost two years after demonstration: $40,000

Variables Used in Calculation:

Carbon Intensity

From Table MSF App D2: Fuel Carbon Intensity Values

CI = Carbon Intensity

$CI_{diesel} = \frac{102.76\ g\ CO2e}{MJ}$ Table Pathway Identifier ULSD001

From Table MSF App D2: Fuel Carbon Intensity Values

$CI_{hydrogen} = \frac{89.94\ g\ CO2e}{MJ}$ Pathway Identifier HYGN005

Energy Density

From Table MSF App D1: Fuel Energy Density

ED = Energy Density

$ED_{diesel} = \frac{134.47\ MJ}{gal\ diesel}$ $ED_{hydrogen} = \frac{120.00\ MJ}{kg\ H2}$

Energy Efficiency Ratio

From Table MSF App D3: EER Values for Fuels Used in Light- Medium- and Heavy-Duty Applications

EER = Energy Efficiency Ratio (unit less)

$EER_{hydrogen}$ = 1.9

Step 1: Convert the diesel used per year to the amount of hydrogen needed to do the same work. Using Formula 3 and the variable identified above.

Formula 3:

$$= \left(\frac{X\ gal\ Diesel}{yr}\right)\left(ED\ \frac{MJ}{1\ gal\ diesel}\right) * \left(ED\,\frac{NF\ unit}{MJ}\right) * \left(\frac{1}{EER}\right)$$

Where:
X is the number of gallons diesel fuel used as a basis for the conversion;
NF is the new fuel that is proposed to be used as a diesel replacement;
ED is the Energy Density of the replacement fuel see Table MSF App D1: Fuel Energy Density; and
Unit is the units associated with the replacement fuel:

Electricity: kWh
Hydrogen: kg
CNG: scf

$$\frac{kg\ H2}{year} = \left(\frac{1664\ gal\ diesel}{year}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{1\ kg\ H2}{120.00\ MJ}\right) * \left(\frac{1}{1.9}\right) = 981\ \frac{kg\ H2}{year}$$

Step 2: Determine the GHG emissions that are attributed to the base case diesel fueled TRU. Using Formula 1 and the variables identified above.

Formula 1:

$$GHG\ EF = carbon\ intensity * \frac{fuel\ energy\ density}{efficiency} * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{MJ}{gal}\ or\ \frac{MJ}{kg}\ or\ \frac{MJ}{scf}\right) * \left(\frac{gal}{day}\ or\ \frac{kg}{day}\ or\ \frac{scf}{day}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$GHG\ EF_{base} = \left(\frac{102.76\ g\ CO2e}{MJ}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{1664\ gal}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right) = 23\ \frac{metric\ tonc\ CO2e}{year}$$

Step 3: Determine the GHG emissions that are attributed to the advanced technology TRU. Using Formula 1, the result from Step 1 and the variables identified above.

GHG $EF_{adv\ tech} = \left(\frac{89.94\ g\ CO2e}{MJ}\right) * \left(\frac{120.00\ MJ}{kg\ H2}\right) * \left(\frac{981\ kg\ H2}{year}\right) * \left(\frac{1\ metric\ ton}{1{,}000{,}000\ grams}\right) = 11\frac{metric\ tons\ CO2e}{year}$

Step 4: Determine the GHG emission reductions that are associated with the proposed project. Using Formula 4, populated by results from Step 2 and Step 3 to give the GHG emission benefit from the proposed project.

Formula 4:

Project GHG ER_{annual} = GHG EF_{base} - GHG $EF_{adv\ tech}$

Project GHG ER $_{annual}$ = $\left(\frac{23\ metric\ tons\ CO2e}{year}\right) - \left(\frac{11\ metric\ tons\ CO2e}{year}\right) = 12\ \frac{metric\ tons\ CO2e}{year}$

Step 5: Determine the annual criteria pollutant emission reductions that are associated with the proposed project. The base case TRU is using a 24 hp, diesel engine that is certified to the Tier-4 final emissions standard, therefore, using emission values from Table D-12 and fuel consumption rate factors from Table D-24, the result of Step1 above to populate Formula C-8. The fuel cell TRU will be used 100% of the time in California. There are no criteria pollutant emissions associated with the use of the fuel cell TRU in a tank to wheel analysis.

For a Tier-4 final off-road engine at 24 hp, Table D-12 gives criteria pollutant emissions per bhp-hr, but only for diesel engines above 25 hp, for this calculation use the emission factor for a 25 hp diesel engine. The conversion factor from Table D-24, for the relevant engine power rating, allows for the conversion from gram per bhp-hr to gram per gallon of fuel consumed. Therefore:

NOx = 2.75 $\frac{g\ NOx}{bhp-hr}$; ROG =0.12 $\frac{g\ ROG}{bhp-hr}$; PM10 = 0.008 $\frac{g\ PM\ 10}{bhp-hr}$

Formula C-8: Estimated Annual Emissions based on Fuel Consumed using Emission Factors or Converted Emission Standard (tons/yr)

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * fuel consumption rate factor (bhp-hr/gallon (gal)) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

Annual ER is the annual emission reductions for a particular pollutant.

Annual ER_{NOx} = $\left(\frac{2.75g\ NOx}{bhp-hr}\right) * \left(\frac{18.5\ bhp-hr)}{gal\ diesel}\right) * \left(\frac{1664\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) =$

Annual ER_{NOx} = $0.093\,\frac{tons\ NOx}{year}$

Annual ER_{ROG} = $(\frac{0.12\ g\ ROG}{bhp-hr}) * \left(\frac{18.5\ bhp-hr)}{gal\ diesel}\right) * \left(\frac{1664\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) =$

Annual $ER_{ROG} = 0.0041\ \frac{tons\ ROG}{year}$

Annual ER_{PM} = $\left(\frac{0.008\ g\ PM}{bhp-hr}\right) * \left(\frac{18.5\ bhp-hr)}{gal\ diesel}\right) * \left(\frac{1664 gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) =$

Annual ER_{PM} = $0.00027\,\frac{tons\ PM}{year}$

Step 6: Determine the weighted annual surplus emission reductions that are associated with the proposed project. Using the results from Step 5 above along with the realization that the proposed fuel cell TRU will not produce any criteria pollutant emissions in a tank-to-wheel scenario populate Formula C-5.

Formula C-5: Annual Weighted Surplus Emission Reductions (tons/yr)

WER is the Weighted Emission Reductions

Weighted Emission Reductions =

*NOx reductions (tons/yr) + ROG reductions (tons/yr) + [20 * (PM reductions (tons/yr)]*

Therefore, using the results from Step 6 above and Formula C-5:

WER = $(0.093\,\frac{tons\ NOx}{year}) + \left(\ 0.0041\ \frac{tons\ ROG}{year}\right) * 20\left(0.00027\,\frac{tons\ PM}{year}\right) = 0.10\ \frac{tons}{year}$

Therefore, WER = 0.10 $\frac{tons\ criteria\ pollutants\ reduced}{year}$

Step 7: Determine the incremental cost of the proposed technology using Formula C-3, the equipment costs for the base case TRU and the fuel cell TRU given at the start of this example. Cost effectiveness is to be calculated for two scenarios; for two years during the demonstration and for 10 years, two years after the completion of the demonstration project.

Baseline Equipment:

- TRU cost at demonstration: $26,000
- TRU cost two years after demonstration: $26,000

Advanced Technology:

- TRU cost at demonstration: $45,000
- TRU cost two years after demonstration: $40,000

Formula C-3: Incremental Cost ($)

Incremental Cost = Cost of New Technology ($) – Cost of Baseline Diesel Technology ($)

$\text{Incremental Cost}_{2\ years}$ = $45,000 - $26,000 = $19,000

$\text{Incremental Cost}_{10\ years}$ = $40,000 - $26,000 = $14,000

Step 8: Determine the GHG emission reduction cost effectiveness for the proposed project using the results from Step 4, Step 7 and Formula 5

Formula 5:

$$Cost\ Effectiveness\ \left(\frac{\$}{metric\ ton}\right) = \left(\frac{\left(\frac{CRF * (\$Advanced\ Technology\ Vehicle - \$Baseline\ Diesel\ Vehicle}{year}\right)}{\left(\frac{metric\ ton\ emissions\ reduced}{year}\right)}\right)$$

For the purposes of this Solicitation:

CRF is the Capital Recover Factor for a specific useful life.

CRF_2 = 0.515 per Moyer Table G-3b (2-year life)

CRF_{10} = 0.111 per Moyer Table G-3b (10-year life)

Therefore:

GHG C/E is the GHG Cost Effectiveness

$$\text{GHG C/E}_{2\ years} = \left(\frac{\frac{(0.515 * \$19{,}000)}{year}}{\frac{12\ metric\ tons\ CO2e}{year}}\right) = \frac{\$815}{metric\ tons\ CO2e\ reduced}$$

$$\text{GHG C/E}_{10\ years} = \left(\frac{\left(\frac{(0.111 * \$14{,}000)}{year}\right)}{\frac{12\ metric\ tons\ CO2e}{year}}\right) = \frac{\$130}{metric\ tons\ CO2e\ reduced}$$

Step 9: Determine the criteria pollutant cost effectiveness for the proposed technology. Use the results from Step 6 and Step 7 to populate Formula C-1.

Formula C-1: Cost-Effectiveness of Weighted Surplus Emission Reductions ($/ton):

$$\textit{Cost-Effectiveness (\$/ton)} = \frac{\textit{Annualized Cost (\$/year(yr))}}{\textit{Annual Weighted Surplus Emission Reductions (tons/yr)}}$$

$$\text{Criteria Pollutant C/E}_{\text{2 years}} = ((\frac{\frac{(0.515*\$19{,}000)}{year}}{\frac{0.10\ tons\ WER}{year}}) = \frac{\$97{,}850}{tons\ criteria\ pollutants\ reduced}$$

$$\text{Criteria Pollutant C/E}_{\text{10 years}} = ((\frac{\frac{(0.111*\$14{,}000)}{year}}{\frac{0.10\ tons\ WER}{year}}) = \frac{\$15{,}540}{tons\ criteria\ pollutants\ reduced}$$

Example 3: Battery Electric Heavy Lift Forklift

Potential GHG emission reductions are determined on a well-to-wheel basis, while criteria pollutant emission reductions are determined using a tank-to-wheel analysis. This example assumes that a heavy-lift forklift will have the same energy requirements as a diesel counterpart and will be used the same number of hours. Electricity to charge the proposed forklift will come from the electrical grid.

Baseline Diesel Forklift:

- Off-Road diesel engine: Tier-4 initial certification, 110 hp
- 19,000 lbs. lift capacity
- Diesel usage: 13 gallons per week, 676 gal per year
- Forklift cost at demonstration: $40,000
- Forklift cost two years after demonstration: $40,000

Advanced Technology:

- Battery-electric forklift
- Forklift cost at demonstration: $75,000
- Forklift cost two years after demonstration: $65,000

Variables Used in Calculation:

Carbon Intensity

From Table MSF App D2: Fuel Carbon Intensity Values

CI = Carbon Intensity

$CI_{diesel} = \frac{102.76\ g\ CO2e}{MJ}$ Table Pathway Identifier ULSD001

From Table MSF App D2: Fuel Carbon Intensity Values

$CI_{electricity} = \frac{105.16\ g\ CO2e}{MJ}$ Pathway Identifier ELC001

Energy Density

From Table MSF App D1: Fuel Energy Density

ED = Energy Density

$ED_{diesel} = \frac{134.47\ MJ}{gal\ diesel}$ $ED_{electricity} = \frac{3.60\ MJ}{Kw-hr}$

Energy Efficiency Ratio

From Table MSF App D3: EER Values for Fuels Used in Light- Medium- and Heavy-Duty Applications

EER = Energy Efficiency Ratio (unit less)

$EER_{electricity}$ = 3.8

Step 1: Convert the diesel used per year to the amount of electricity needed to do the same work. Using Formula 3 and the variable identified above.

Formula 3:

$$= \left(\frac{X\ gal\ Diesel}{yr}\right)\left(ED\ \frac{MJ}{1\ gal\ diesel}\right) * \left(ED\ \frac{NF\ unit}{MJ}\right) * \left(\frac{1}{EER}\right)$$

Where:

X is the number of gallons diesel fuel used as a basis for the conversion;
NF is the new fuel that is proposed to be used as a diesel replacement;
ED is the Energy Density of the replacement fuel see Table MSF App D1: Fuel Energy Density; and
Unit is the units associated with the replacement fuel:

Electricity: kWh
Hydrogen: kg
CNG: scf

$$\frac{Kw-hr}{year} = \left(\frac{676\ gal\ diesel}{year}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{1\ Kw-hr}{3.60MJ}\right) * \left(\frac{1}{3.8}\right) = 6{,}645\ \frac{Kw-hr}{year}$$

Step 2: Determine the GHG emissions that are attributed to the base case diesel fueled heavy-lift forklift. Using Formula 1 and the variables identified above.

Formula 1:

$$GHG\ EF = carbon\ intensity * \frac{fuel\ energy\ density}{efficiency} * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{MJ}{gal}\ or\ \frac{MJ}{kg}\ or\ \frac{MJ}{scf}\right) * \left(\frac{gal}{day}\ or\ \frac{kg}{day}\ or\ \frac{scf}{day}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$GHG\ EF_{base} = \left(\frac{102.76\ g\ CO2e}{MJ}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{676\ gal}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right) = 9.3\ \frac{metric\ tons\ CO2e}{year}$$

Step 3: Determine the GHG emissions that are attributed to the advanced technology forklift. Using Formula 2, the result from Step 1 and the variables identified above.

Formula 2:

$$GHG\ EF = \frac{metric\ ton\ CO2e}{year} = carbon\ intensity * unit\ conversion * efficiency$$

$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{3.60\ MJ}{kWh}\right) * \left(\frac{X\ kWh}{year}\right) * \frac{1\ metric\ ton}{1{,}000{,}000\ grams}$$

GHG $EF_{adv\ tech}$ = $\left(\frac{105.16\ g\ CO2e}{MJ}\right) * \left(\frac{3.60\ MJ}{kWh}\right) * \left(\frac{6645\ Kw{-}hr}{year}\right) * \left(\frac{1\ metric\ ton}{1{,}000{,}000\ grams}\right)$

GHG $EF_{adv\ tech}$ = $2.5\,\frac{metric\ tons\ CO2e}{year}$

Step 4: Determine the GHG emission reductions that are associated with the proposed project. Using Formula 4, populated by results from Step 2 and Step 3 above to give the GHG emission benefit from the proposed project.

Formula 4:

Project GHG ER_{annual} = GHG EF_{base} - GHG $EF_{adv\ tech}$

Project GHG ER_{annual} = $\left(\frac{9.3\ metric\ tons\ CO2e}{year}\right) - \left(\frac{2.5\ metric\ tons\ CO2e}{year}\right) = 6.8\ \frac{metric\ tons\ CO2e}{year}$

Step 5: Determine the annual criteria pollutant emission reductions that are associated with the proposed project. The base case diesel fueled forklift is using a 110 hp diesel engine that is certified to the Tier-4 initial emissions standard, therefore, using emission values from Table D-12 and fuel consumption rate factors from Table D-24, the result of Step1 above to populate Formula C-8. The forklift will be used 100% of the time in California. There are no criteria pollutant emissions associated with the use of the battery-electric forklift in a tank to wheel analysis.

For a Tier-4 initial off-road engine at 110 hp, Table D-12 gives criteria pollutant emissions per bhp-hr, the conversion factor from Table D-24, or the relevant sized engine, allows for the conversion from gram per bhp-hr to gram per gallon of fuel consumed. Therefore:

NOx = $2.14\ \frac{g\ NOx}{bhp{-}hr}$; ROG =$0.11\ \frac{g\ ROG}{bhp{-}hr}$; PM10 = $0.008\ \frac{g\ PM\ 10}{bhp{-}hr}$

Formula C-8: Estimated Annual Emissions based on Fuel Consumed using Emission Factors or Converted Emission Standard (tons/yr)

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * fuel consumption rate factor (bhp-hr/gallon (gal)) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

Annual ER_{NOx} = $\left(\frac{2.14g\ NOx}{bhp-hr}\right) * \left(\frac{18.5\ bhp-hr)}{gal\ diesel}\right) * \left(\frac{676\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) =$

Annual ER_{NOx} = 0.030 $\frac{tons\ NOx}{year}$

Annual ER_{ROG} = $\left(\frac{0.11\ g\ ROG}{bhp-hr}\right) * \left(\frac{18.5\ bhp-hr)}{gal\ diesel}\right) * \left(\frac{676\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) =$

Annual ER_{ROG} = $0.0015\ \frac{tons\ ROG}{year}$

Annual ER_{PM10} = $\left(\frac{0.008\ g\ PM\ 10}{bhp-hr}\right) * \left(\frac{18.5\ bhp-hr)}{gal\ diesel}\right) * \left(\frac{676\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) =$

Annual ER_{PM10} = $0.00011\ \frac{tons\ PM}{year}$

Step 6: Determine the weighted annual surplus emission reductions that are associated with the proposed project. Using the results from Step 5 above along with the realization that the proposed battery-electric forklift will not produce any criteria pollutant emissions in a tank-to-wheel scenario, populate Formula C-5.

Formula C-5: Annual Weighted Surplus Emission Reductions (tons/yr)

WER is the Weighted Emission Reductions

Weighted Emission Reductions =

*NOx reductions (tons/yr) + ROG reductions (tons/yr) + [20 * (PM reductions (tons/yr)]*

Therefore, using the results from Step 6 above and Formula C-5:

WER = $(0.030\frac{tons\ NOx}{year}) + \left(0.0015\ \frac{tons\ ROG}{year}\right) * 20\left(0.00011\frac{tons\ NOx}{year}\right) = 0.034\ \frac{tons}{year}$

Therefore, WER = 0.034 $\frac{tons\ criteria\ pollutants\ reduced}{year}$

Step 7: Determine the incremental cost of the proposed technology using Formula C-3 and the equipment costs for the base case diesel fueled forklift and the battery-electric heavy lift forklift given at the start of this example. Cost effectiveness is to be calculated for two scenarios; for two years during the demonstration and for 10 years, two years after the completion of the demonstration project.

Baseline Equipment:

- Forklift cost at Demonstration: $40,000
- Forklift cost two years after demonstration: $40,000

Advanced Technology:

- Forklift cost at demonstration: $75,000
- Forklift cost two years after demonstration: $65,000

Formula C-3: Incremental Cost ($)

Incremental Cost = Cost of New Technology ($)–Cost of Baseline Diesel Technology ($)

Incremental $\text{Cost}_{2\ \text{years}}$ = $75,000 - $40,000 = $35,000

Incremental $\text{Cost}_{10\ \text{years}}$ = $65,000 - $40,000 = $25,000

Step 8: Determine the GHG emission reduction cost effectiveness for the proposed project using the results from Step 4, Step 7 and Formula 5

Formula 5:

CRF is the Capitol Recovery Factor

$$Cost\ Effectiveness\ \left(\frac{\$}{metric\ ton}\right) = \left(\frac{\left(\frac{CRF * (\$Advanced\ Technology\ Vehicle - \$Baseline\ Diesel\ Vehicle}{year}\right)}{\left(\frac{metric\ ton\ emissions\ reduced}{year}\right)}\right)$$

For the purposes of this Solicitation:

CRF_2 = 0.515 per Moyer Table G-3b (2-year life)

CRF_{10} = 0.111 per Moyer Table G-3b (10-year life)

Therefore:

GHG C/E is the GHG Cost Effectiveness

$$\text{GHG C/E}_{\text{2 years}} = \left(\frac{\frac{(0.515 * \$35{,}000)}{year}}{\frac{6.8\ metric\ tons\ CO2e}{year}}\right) = \frac{\$2651}{metric\ tons\ CO2e\ reduced}$$

$$\text{GHG C/E}_{\text{10 years}} = \left(\frac{\left(\frac{(0.111 * \$25{,}000)}{year}\right)}{\frac{6.8\ metric\ tons\ CO2e}{year}}\right) = \frac{\$408}{metric\ tons\ CO2e\ reduced}$$

Step 9: Determine the criteria pollutant cost effectiveness for the proposed technology. Use the results from Step 6 and Step 7 to populate Formula C-1.

Formula C-1: Cost-Effectiveness of Weighted Surplus Emission Reductions ($/ton)

$$\textit{Cost-Effectiveness (\$/ton)} = \frac{\textit{Annualized Cost (\$/year(yr))}}{\textit{Annual Weighted Surplus Emission Reductions (tons/yr)}}$$

$$\text{Criteria Pollutant C/E}_{\text{2 years}} = ((\frac{\frac{(0.515 * \$35{,}000)}{year}}{\frac{0.034\ tons\ WER}{year}}) = \frac{\$530{,}000}{tons\ criteria\ pollutants\ reduced}$$

$$\text{Criteria Pollutant C/E}_{\text{10 years}} = ((\frac{\frac{(0.111 * \$25{,}000)}{year}}{\frac{0.034\ tons\ WER}{year}}) = \frac{\$81{,}600}{tons\ criteria\ pollutants\ reduced}$$

Example 4: Battery-Electric Regional Haul On-Road Truck with Internal Combustion Range Extender

Potential GHG emission reductions are determined on a well-to-wheel basis, while criteria pollutant emission reductions are determined using a tank-to-wheel analysis. This example assumes that an internal combustion range extending battery-electric on-road heavy-duty truck will have the same energy requirements as a diesel counterpart and will be used the same number of miles. Further, it is assumed that this project will use electricity for on-board battery charging and on-board CNG for the range extending internal combustion engine. It is assumed that 2/3rds of the advanced technology vehicle's energy needs will come from the on-board battery pack and that 1/3 of the trucks energy needs will come from the on-board range extending engine. The CNG will be 85% pipeline and 15% renewable from high solids anaerobic digestion of food and green wastes.

This example demonstrates the use of two fuel types in one advanced technology application with one of those fuel types, CNG, having a composite Carbon Intensity that is not directly given in Table MSF App D2: Fuel Carbon Intensity Values, but rather needs to be calculated.

Baseline On-Road Truck:

- 2010 on-road heavy duty diesel emission standard compliant engine
- Fuel usage is 7 miles per gallon at 150 miles per day for 210 days a year
- On-road truck cost at Demonstration: $100,000
- On-road truck cost two years after demonstration: $100,000

Advanced Technology:

- CNG range extending battery dominant on-road truck
- CNG range extending engine meet the 2010 heavy-duty diesel emission standard of 0.20 gram NOx per bhp-hr
- Truck cost at demonstration: $750,000
- Truck cost two years after demonstration: $550,000

Variables Used in Calculation:

Carbon Intensity

From Table MSF App D2: Fuel Carbon Intensity Values

CI = Carbon Intensity

$CI_{diesel} = \frac{102.76\ g\ CO2e}{MJ}$ Table Pathway Identifier ULSD001

From Table MSF App D2: Fuel Carbon Intensity Values

$CI_{electricity} = \frac{105.16\ g\ CO2e}{MJ}$ Pathway Identifier ELC001

$CI_{pipeline\ cng} = \frac{79.46\ g\ CO2e}{MJ}$ Pathway Identifier CNG002

$CI_{renewable\ cng} = \frac{-34.70\ g\ CO2e}{MJ}$ Pathway Identifier CNG0005

Energy Density

From Table MSF App D1: Fuel Energy Density

ED = Energy Density

$ED_{diesel} = \frac{134.47\ MJ}{gal\ diesel}$ $ED_{electricity} = \frac{3.60\ MJ}{Kw-hr}$ $ED_{cng} = \frac{0.98\ MJ}{scf}$

Energy Efficiency Ratio

From •Table MSF App D3: EER Values for Fuels Used in Light- Medium- and Heavy-Duty Applications

EER = Energy Efficiency Ratio (unit less)

The EER for electricity in use on electric, battery electric or hybrid electric trucks are selected and the EER for CNG in spark ignition engines. Those EER values are show below:

$EER_{\ electricity} = 2.7$ $EER_{\ cng} = 0.9$

Conversion for CNG Standard Cubic Feet (scf) to Diesel Gallon Equivalent (DGE)

For the purpose of this solicitation assume:

1 DGE = 139.30 scf CNG[5]

Step 1: Calculate the baseline on-road trucks annual fuel usage:

$$\frac{gal\ diesel}{year} = \left(\frac{1 gallon}{7\ miles}\right) * \left(\frac{150\ miles}{yearday}\right)\left(\frac{210\ days}{year}\right) = \frac{4500\ gallons\ diesel}{year}$$

Step 2: Convert the diesel used per year to the amount of electricity and CNG needed to do the same work. Using Formula 3, the variable identified above and the realization

[5] CNG scf to DGE conversion Source: U.S. Department of Energy Alternative Fuels Data Center http://www.afdc.energy.gov/fuels/equivalency_methodology.html

that 2/3 of the energy needs of the truck will come from electricity and 1/3 of the energy needs will come from CNG. .

Formula 3:

$$= \left(\frac{X\ gal\ Diesel}{yr}\right)\left(ED\ \frac{MJ}{1\ gal\ diesel}\right) * \left(ED\,\frac{NF\ unit}{MJ}\right) * \left(\frac{1}{EER}\right)$$

Where:
X is the number of gallons diesel fuel used as a basis for the conversion;
NF is the new fuel that is proposed to be used as a diesel replacement;
ED is the Energy Density of the replacement fuel see Table MSF App D1: Fuel Energy Density; and
Unit is the units associated with the replacement fuel:

Electricity: kWh
Hydrogen: kg
CNG: scf

First calculate the number of kilowatt hours needed to supply the power needs for 2/3rds of the diesel.

Electric need = $0.67 * 4500\ gallons$ = 3015 gallons diesel

CNG need = $0.33 * 4500\ gallons$= 1485 gallons diesel

$$Electricity = \left(\frac{3015\ gal\ diesel}{year}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{1\ Kw{-}hr}{3.60MJ}\right)*\left(\frac{1}{2.7}\right) = 41{,}711\ \frac{Kw{-}hr}{year}$$

$$CNG = \left(\frac{1485\ gal\ diesel}{year}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{1\ scf}{0.98MJ}\right)*\left(\frac{1}{0.9}\right) = 226{,}404\ \frac{scf}{year}$$

Step 3: Determine the GHG emissions that are attributed to the base case diesel fueled on-road truck. Using Formula 1 and the variables identified above.

Formula 1:

$$GHG\ EF = carbon\ intensity * \frac{fuel\ energy\ density}{efficiency} * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{MJ}{gal}\ or\ \frac{MJ}{kg}\ or\ \frac{MJ}{scf}\right) * \left(\frac{gal}{day}\ or\ \frac{kg}{day}\ or\ \frac{scf}{day}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$GHG\ EF_{base} = \left(\frac{102.76\ g\ CO2e}{MJ}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{4500\ gal}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right) = 62\ \frac{metric\ tons\ CO2e}{year}$$

Step 4: Determine the composite Carbon Intensity value for the CNG blend that is proposed to be used in this project. The proposal for this project will use 85% pipeline CNG and 15% renewable CNG from anaerobic digestion of food and green waste. Use Formula 6 for this calculation.

Formula 6:

$$CI_{composite} = (Fraction\ of\ total\ fuel * (CI\ fuel\ 1)) + (fraction\ of\ total\ fuel * (CI\ Fuel\ 2))$$

$$CI_{cng\ composite} = (\frac{2}{3} * (\frac{79.46\ g\ CO2e}{MJ})) + (\frac{1}{3} * (\frac{-34.70\ g\ CO2e}{MJ})) = \frac{41.79\ g\ CO2e}{MJ}$$

Use this result for the Carbon Intensity calculations using CNG.

Step 5: Determine the well-to-wheel GHG emissions that are attributed to the advanced technology on-road truck. This calculation will need to be performed for each of the two fuel types that will be used in the proposed advanced technology on-road truck. Using Formula 1 and Formula 2, the result from Step 2, the composite CI value determined in Step 4 and the variables identified above, calculate the GHG emissions associated with the advanced technology on-road truck. .

Formula 1: Liquid / Natural Gas and Hydrogen Fueled Vehicles

$$GHG\ EF = carbon\ intensity * \frac{fuel\ energy\ density}{efficiency} * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

$$= (\frac{gram\ CO2e}{MJ}) * \left(\frac{MJ}{gal}\ or\ \frac{MJ}{kg}\ or\ \frac{MJ}{scf}\right) * \left(\frac{gal}{day}\ or\ \frac{kg}{day}\ or\ \frac{scf}{day}\right) * (\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams})$$

Formula 2: Electric Vehicles

$$GHG\ EF = \frac{metric\ ton\ CO2e}{year} = carbon\ intensity * unit\ conversion * efficiency$$

$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{3.60\ MJ}{kWh}\right) * \left(\frac{X\ kWh}{year}\right) * \frac{1\ metric\ ton}{1{,}000{,}000\ grams}$$

$$= (\frac{gram\ CO2e}{MJ}) * \left(\frac{MJ}{gal}\ or\ \frac{MJ}{kg}\ or\ \frac{MJ}{scf}\right) * \left(\frac{gal}{day}\ or\ \frac{kg}{day}\ or\ \frac{scf}{day}\right) * (\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams})$$

Formula 2 will be used for the electric portion of the energy requirements.

$$GHG\ EF_{adv\ tech\ electricity} = \left(\frac{105.16\ g\ CO2e}{MJ}\right) * \left(\frac{3.60\ MJ}{kWh}\right) * \left(\frac{41{,}711\ kWh}{year}\right) * \frac{1\ metric\ ton}{1{,}000{,}000\ grams}$$

GHG $EF_{\text{adv tech electricity}} = 15.8 \frac{metric\ tons\ CO2e}{year}$

Formula 1 will be used for the CNG energy portion of the energy requirements

GHG $EF_{\text{adv tech CNG}} = \left(\frac{41.79\ g\ CO2e}{MJ}\right) * \left(\frac{0.98\ MJ}{scf}\right) * \left(\frac{226{,}404\ scf}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right) =$

GHG $EF_{\text{adv tech CNG}} = 9.3\ \frac{metric\ tons\ CO2e}{year}$

Sum the GHG emissions from the electricity and the CNG to get the total GHG emissions from the advanced technology truck.

GHG $EF_{\text{adv tech}} = 15.8 \frac{metric\ tons\ CO2e}{year} + 9.3\ \frac{metric\ tons\ CO2e}{year} = 25\ \frac{metric\ tons\ CO2e}{year}$

Step 6: Determine the annual GHG emission reductions that are associated with the proposed project. Using Formula 4 above populated by results from Step 4 and Step 5 from the above example to give the annual GHG emission benefit from the proposed project.

Formula 4:

Project GHG ER_{annual} = GHG EF_{base} - GHG $EF_{\text{adv tech}}$

Project GHG $ER_{\text{annual}} = (\frac{62\ metric\ tons\ CO2e}{year}) - \left(\frac{25\ metric\ tons\ CO2e}{year}\right) = 37\ \frac{metric\ tons\ CO2e}{year}$

Step 7: Determine the annual criteria pollutant emission reductions that are associated with the proposed project. The base case diesel on-road truck meeting 2010 emission standard, therefore, using emission values from Table D-12 and fuel consumption rate factors from Table D-24, the result of Step1 above to populate Formula C-8. The trucks will be used 100% of the time in California. There are criteria pollutant emissions associated with the use of the advanced technology truck and therefore those emissions need to be considered.

For an on-road 2010 emission standard diesel heavy duty truck Table D-12 gives criteria pollutant emissions per bhp-hr, the conversion factor, for the relevant engine hp from Table D-24 allows for the conversion from gram per bhp-hr to gram per gallon of fuel consumed. Therefore:

NOx = $2.32\ \frac{g\ NOx}{bhp-hr}$; ROG = $0.12\ \frac{g\ ROG}{bhp-hr}$; PM10 = $0.008\ \frac{g\ PM\ 10}{bhp-hr}$

Formula C-8: Estimated Annual Emissions based on Fuel Consumed using Emission Factors or Converted Emission Standard (tons/yr)

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * fuel consumption rate factor (bhp-hr/gallon (gal)) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

$$\text{Annual Em}_{NOx} = \left(\frac{2.32 g\ NOx}{bhp-hr}\right) * \left(\frac{18.5\ bhp-hr)}{gal\ diesel}\right) * \left(\frac{4500\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) =$$

$$\text{Annual Em}_{NOx} = 0.21\ \frac{tons\ NOs}{year}$$

$$\text{Annual Em}_{ROG} = \left(\frac{0.12\ g\ ROG}{bhp-hr}\right) * \left(\frac{18.5\ bhp-hr)}{gal\ diesel}\right) * \left(\frac{4500\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) =$$

$$\text{Annual Em}_{ROG} = 0.011\ \frac{tons\ ROG}{year}$$

$$\text{Annual Em}_{PM10} = \left(\frac{0.008\ g\ PM\ 10}{bhp-hr}\right) * \left(\frac{18.5\ bhp-hr)}{gal\ diesel}\right) * \left(\frac{4500\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) =$$

$$\text{Annual ER}_{PM10} = 0.00073\ \frac{tons\ PM}{year}$$

Step 8: Calculate the criteria pollutant emissions that are associated with the advanced technology on-road truck. Since the proposed heavy-duty on-road range extending battery dominant truck has criteria pollutant emissions associated with its operation those emissions need to be determined and subtracted from the emissions from the base case diesel truck calculated in Step 7 above. Using inputs from Table D-2 with the understanding that the CNG range extending engine is an on-road engine certified to the 2010 emission standard for NOx at 0.20 g per bhp-hr and DGE is diesel gallons equivalent. Therefore, Table D-2 gives:

NOx = 3.70 $\frac{g\ NOx}{DGE}$ ROG = 1.17 $\frac{g\ NOx}{DGE}$ PM = 0.185 $\frac{g\ PM}{DGE}$

To calculate the DGE for the CNG sourced emissions from the advanced technology truck, for the purpose of this solicitation use the conversion factor of 139.30 scf of CNG per DGE and the output from Step 2 above, therefore:

$$DGE = \left(\frac{1\ DGE}{139.30\ scf}\right) * \left(226{,}404\ \frac{scf}{year}\right) = 1{,}625\ DGE$$

Using Formula C-9 with the criteria pollutant emission levels identified above and the DGE that was calculate above as inputs.

Formula C-9: Estimated Annual Emissions based on Fuel using Emission Factors (tons/yr) (all of the emission reductions are taking place in CA)

Annual Emission Reductions =

*Emission Factor (g/gal) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

ADV Tech Em is the Advanced Technology Criteria pollutant emission factor for the identified criteria pollutant.

ADV Tech Em $_{NOx}$ = $\left(\frac{3.70\ g\ NOx}{gal\ diesel}\right) * \left(\frac{1625\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.0066\,\frac{tons\ NOx}{year}$

ADV Tech Em $_{ROG}$ = $(\frac{1.17\ g\ ROG}{gal\ diesel}) * \left(\frac{1625\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.0021\ \frac{tons\ ROG}{year}$

ADV Tech Em $_{PM10}$ = $\left(\frac{0.185\ g\ NOx}{gal\ diesel}\right) * \left(\frac{1625\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.00033\,\frac{tons\ PM}{year}$

Step 10: Calculate the criteria emission reductions that are associated with the proposed project. The emission reductions that are associated with the use of the advanced technology on-road truck are the criteria pollutant emissions that are associated with the baseline diesel truck, calculated in Step 8 above, minus the criteria pollutant emissions that are associated with the advanced technology truck, calculated in Step 8 above, as follows:

Project ER = Baseline Emissions – Advanced Technology Emissions

Project ER$_{NOX}$ = $(0.21\ \frac{tons\ NOs}{year}) - \left(\ 0.0066\,\frac{tons\ NOx}{year}\right) = 0.20\ \frac{tons\ NOx}{year}$

Project ER$_{ROG}$ = $(0.011\ \frac{tons\ ROG}{year}) - (0.0021\ \frac{tons\ ROG}{year}) = 0.0089\ \frac{tons\ ROG}{year}$

Project ER$_{PM}$ = $(0.00073\,\frac{tons\ PM}{year}) - \left(\ 0.00033\,\frac{tons\ PM}{year}\right) = 0.00040\ \frac{tons\ PM}{year}$

Step 11: Determine the weighted annual surplus emission reductions that are associated with the proposed project. Using the results from Step 10 above populate Formula C-5.

Formula C-5: Annual Weighted Surplus Emission Reductions (tons/yr)

WER is the Weighted Emission Reductions

Weighted Emission Reductions =

*NOx reductions (tons/yr) + ROG reductions (tons/yr) + [20 * (PM reductions (tons/yr)]*

Therefore, using the results from Step 6 above and Formula C-5:

WER = $(0.20\,\frac{tons\ NOx}{year}) + \left(\ 0.0089\ \frac{tons\ ROG}{year}\right) * 20\left(0.00040\,\frac{tons\ NOx}{year}\right) = 0.22\ \frac{tons}{year}$

Therefore, WER = 0.22 $\frac{tons\ criteria\ pollutants\ reduced}{year}$

Step 12: Determine the incremental cost of the proposed technology using Formula C-3, the vehicle costs for the base case diesel fueled on-road truck and the range extending battery-dominant advanced technology truck given at the start of this example. Cost effectiveness is to be calculated for two scenarios; for two years during the demonstration and for 10 years, two years after the completion of the demonstration project.

Baseline Equipment:

- On-road diesel truck cost at demonstration: $100,000
- On-road diesel truck cost two years after demonstration: $100,000

Advanced Technology:

- Advanced technology truck cost at demonstration: $750,000
- Advanced technology truck cost two years after demonstration: $550,000

Formula C-3: Incremental Cost ($)

Incremental Cost = Cost of New Technology ($) – Cost of Baseline Diesel Technology ($)

Incremental Cost$_{2\ years}$ = $750,000 - $100,000 = $650,000

Incremental Cost$_{10\ years}$ = $550,000 - $100,000 = $450,000

Step 13: Determine the GHG emission reduction cost effectiveness for the proposed project using the results from Step 5, Step 11 and Formula 5

Formula 5:

$$Cost\ Effectiveness\ (\frac{\$}{metric\ ton}) = \left(\frac{\frac{CRF * (\$Advanced\ Technology\ Vehicle - \$Baseline\ Diesel\ Vehicle)}{year}}{(\frac{metric\ ton\ emissions\ reduced}{year})} \right)$$

For the purposes of this Solicitation:

CFR is the Capital Recover Factor for a specific useful life

CRF$_2$ = 0.515 per Moyer Table G-3b (2-year life)

CRF_{10} = 0.111 per Moyer Table G-3b (10-year life)

Therefore,

GHG C/E is the GHG Cost Effectiveness

$$\text{GHG C/E}_{\text{2 years}} = \left(\frac{\frac{(0.515*\$650{,}000)}{year}}{\frac{37\ metric\ tons\ CO2e}{year}}\right) = \frac{\$9047}{metric\ tons\ CO2e\ reduced}$$

$$\text{GHG C/E}_{\text{10 years}} = \left(\frac{\left(\frac{(0.111*\$450{,}000)}{year}\right)}{\frac{37\ metric\ tons\ CO2e}{year}}\right) = \frac{\$1350}{metric\ tons\ CO2e\ reduced}$$

Step 14: Determine the criteria pollutant cost effectiveness for the proposed technology. Use the results from Step 11 and Step 12 to populate Formula C-1.

Formula C-1: Cost-Effectiveness of Weighted Surplus Emission Reductions ($/ton)

$$\textit{Cost-Effectiveness (\$/ton)} = \frac{\textit{Annualized Cost (\$/year(yr))}}{\textit{Annual Weighted Surplus Emission Reductions (tons/yr)}}$$

$$\text{Criteria Pollutant C/E}_{\text{2 years}} = \left(\left(\frac{\frac{(0.515*\$650{,}000)}{year}}{\frac{0.22\ tons\ WER}{year}}\right) = \frac{\$\ 1.5\ million}{tons\ criteria\ pollutants\ reduced}\right.$$

$$\text{Criteria Pollutant C/E}_{\text{10 years}} = \left(\left(\frac{\frac{(0.111*\$450{,}000)}{year}}{\frac{0.22\ tons\ WER}{year}}\right) = \frac{\$227{,}000}{tons\ criteria\ pollutants\ reduced}\right.$$